Title of Research:

Comparison between THOR Anthropomorphic Test Device and THOR Finite Element Model

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Extended time spent in reduced gravity can cause physiologic deconditioning of astronauts, reducing their ability to sustain excessive forces during dynamic phases of spaceflight such as landing. To make certain that the crew is safe during these phases, NASA must take caution when determining what types of landings are acceptable based on the accelerations applied to the astronaut. In order to test acceptable landings, various trials have been run accelerating humans, cadavers, and Anthropomorphic Test Devices (ATDs), or crash test dummies, at different acceleration and velocity rates on a sled testing platform. Using these tests, risks of injury will be created and metrics will be developed for the likelihood of injuries due to the acceleration. A finite element model (FEM) of the Test Device for Human Occupant Restraint (THOR) ATD has been developed that can simulate these test trials and others (Putnam, 2014), reducing the need for human and ATD testing. Additionally, this will give researchers a more effective way to test the accelerations and orientations encountered during spaceflight landings during design of new space vehicles for crewed missions. However, the FEM has not been proven and must be validated by comparing the forces, accelerations, and other measurements of all parts of the body between the physical tests already completed and computer simulated trials.

The purpose of my research was to validate the FEM for the ATD using previously run trials with the physical THOR ATD.

The first part of my research involved processing the data that had already been obtained from the physical trials. While most of the data was available, some kinematic data had to be obtained from the videos taken during the trials using the software program Kinovea. This program allowed the tracking of specific points on the ATD to record displacement throughout the event. All the data for the trials was processed to determine injury criteria and Brinkley Dynamic Response Criterion which is a response criteria that evaluates the risk of injuries from short term accelerations as seen in space flight (Somers et al, 2013). Graphs of accelerations, forces, velocities and other measurements at several points throughout the body and seat were also created. The trials being analyzed were performed in three specific orientations: a frontal (-X) orientation where the occupant was seated upright in the seat and was accelerated rearward, a lateral (-Y) orientation where the occupant was seated upright in the seat and was accelerated from right to left, and a spinal (+Z) orientation where the occupant was seated horizontally similar to laying down and was accelerated upwards or from the feet to the head.

To determine the effectiveness of the FEM, trials were simulated through the model that replicated the same conditions used during the physical tests. A total of 48 physical tests were run with the ATDs and each trial was also tested on the computer model using LS-DYNA, a program capable of simulating the accelerations given to the model. After each test was simulated through LS-DYNA, the results of each simulation were processed in the same manner as the physical tests to allow for an accurate comparison between the two. A program called CORA (Correlation Analysis) was then used to determine how accurately the FEM replicated the physical tests on all the measurements that were taken such as maximum forces, accelerations, and times of these peak forces or accelerations. While it may not seem incredibly difficult to replicate a very short pulse on a crash test dummy using a computer model, there are many different parts of the body, orientations, and types of measurements that were being analyzed. Everything from the head movement to arm and leg flail need to be accounted for when creating the model because the model is meant to simulate exactly how a THOR ATD would respond. All those movements, accelerations, and forces will be present in the real event. CORA was used to give metrics to tell how accurately each of the measurements was for the model. The CORA output graphics and files were used to interpret the results of the FEM.

The results obtained from this project were all of the correlation graphs and metrics from CORA of the FEM. These metrics help put into context how effectively the model reproduced the physical tests. While interpreting this data and determining a conclusion based off of the analysis was not part of this task, the correlation analysis results allowed a rough interpretation the results. There were 48 physical tests and 48 FEM simulations that were correlated with each other. Each correlation had anywhere from 30 to 60 measurements depending on the amount of matching channels present between the physical dummy and the finite model. Not all the matching measurements for each correlation were vital because of the orientation that the test was performed under. In addition, some of the correlation analysis previously performed by those that created the model were replicated and therefore assured that the rest of the trials were accurately compared.

Based on the CORA scores and analysis, the model accurately simulates many of the important measurements such as the head’s center of gravity acceleration in the Z direction during a spinal test. When determining the safety for the astronauts during the dynamic phases of flight the head is an important part to monitor and therefore the model must be able to accurately simulate the head’s response during an acceleration. Overall there were many measurements that were very accurate with the physical tests and several others that were not as accurate as necessary. The correlation analysis will need to be examined to determine if the model is acceptable or if the model must be further optimized to accurately simulate the physical tests. Once this optimization is complete, the model will be compared with the human and cadaver trials that have been run previously to determine risk of injury and appropriate metrics for protecting astronauts. Eventually the model can be used in lieu of or alongside human and physical test devices to determine injury risks and acceptable accelerations or forces encountered during spacecraft landings.

References

Putnam JB, Somers JT, Untaroiu CD. (2014) Development, Calibration, and Validation of a Head-Neck Complex of THOR Mod Kit Finite Element Model. Traffic Injury Prevention. 15:844-54.

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